CERES Angular Distribution Model Working Group Report

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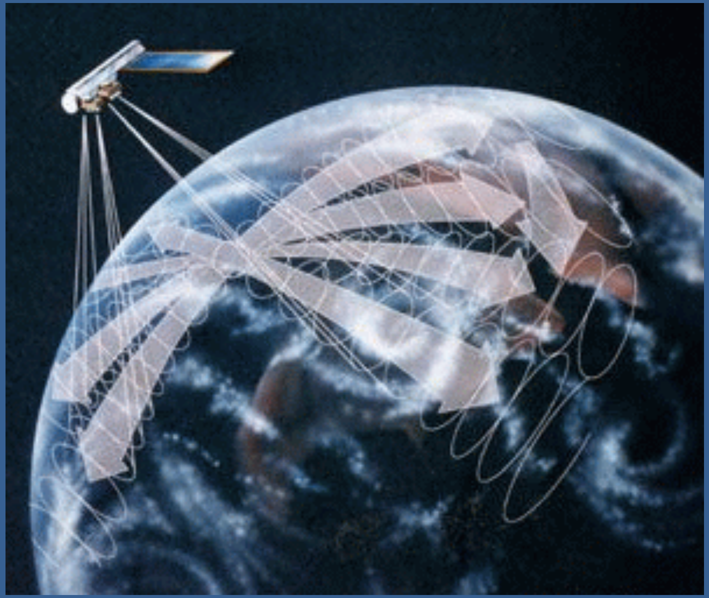
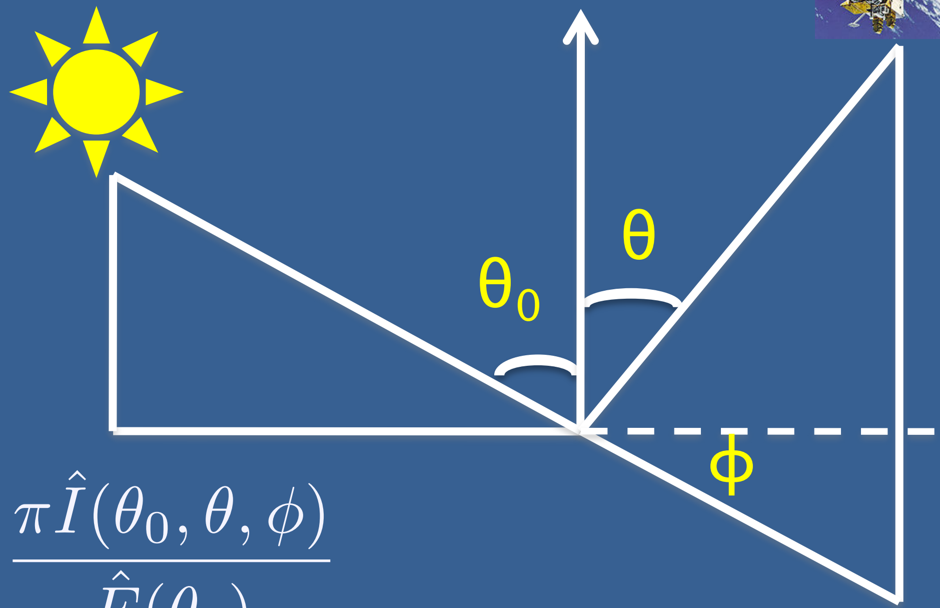


From radiance to flux: angular distribution models

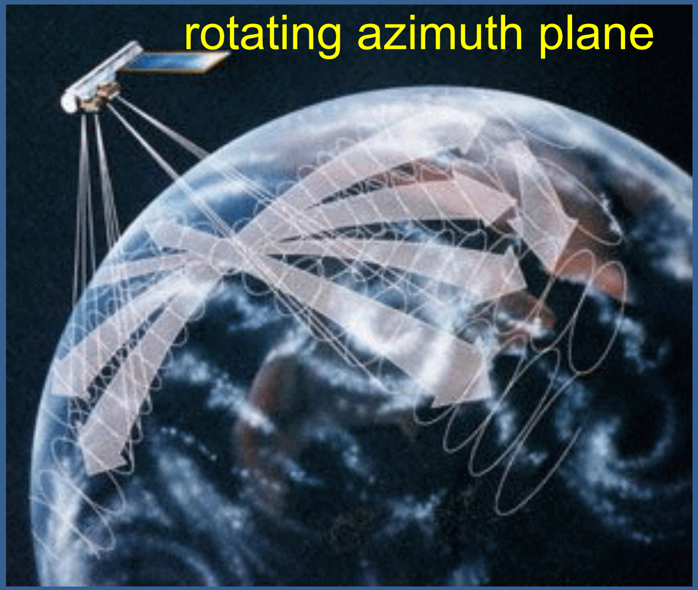
- Sort observed radiances into angular bins over different scene types;
- Integrate radiance over all θ and ϕ to estimate the anisotropic factor for each scene type:



$$R(\theta_0,\theta,\phi) = \frac{\pi \hat{I}(\theta_0,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} \hat{I}(\theta_0,\theta,\phi) cos\theta sin\theta d\theta d\phi} = \frac{\pi \hat{I}(\theta_0,\theta,\phi)}{\hat{F}(\theta_0)}$$

- For each radiance measurement, first determine the scene type, then apply scene type dependent anisotropic factor to observed radiance to derive TOA flux:

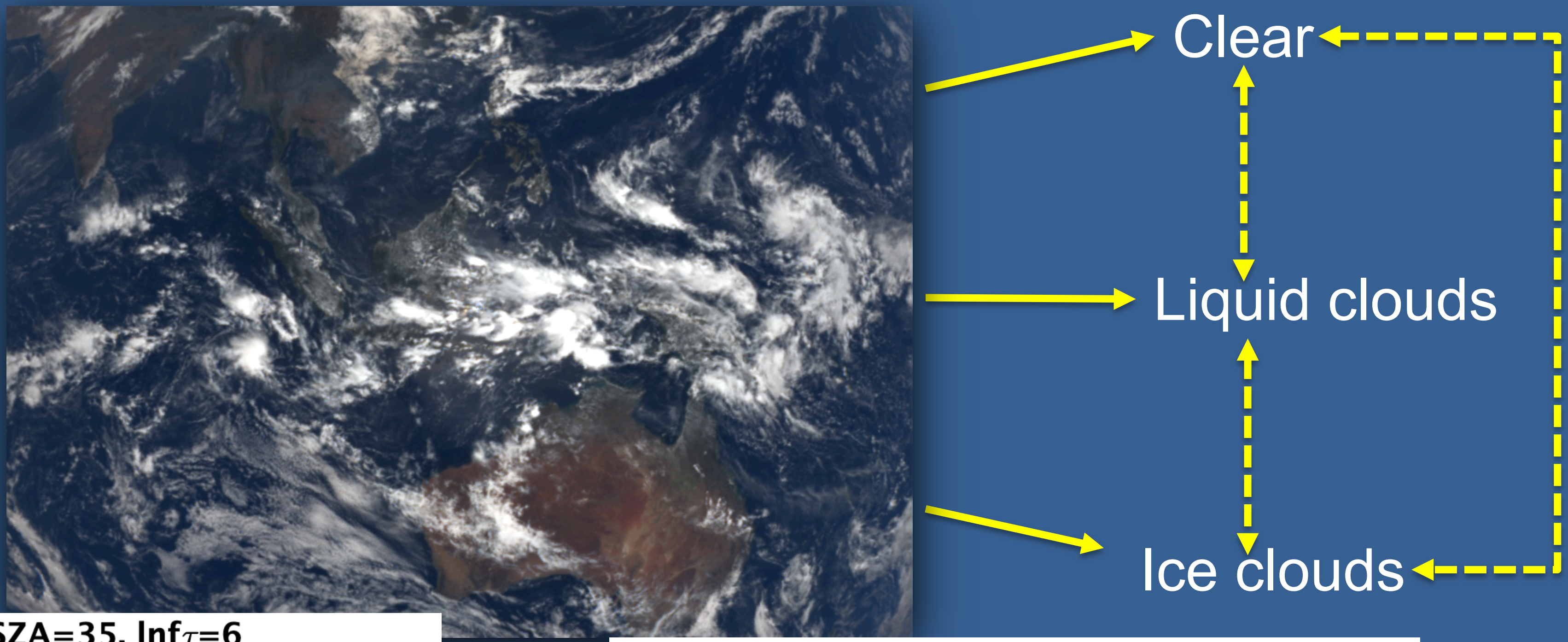
$$F(\theta_0) = \frac{\pi I_o(\theta_0,\theta,\phi)}{R(\theta_0,\theta,\phi)}$$

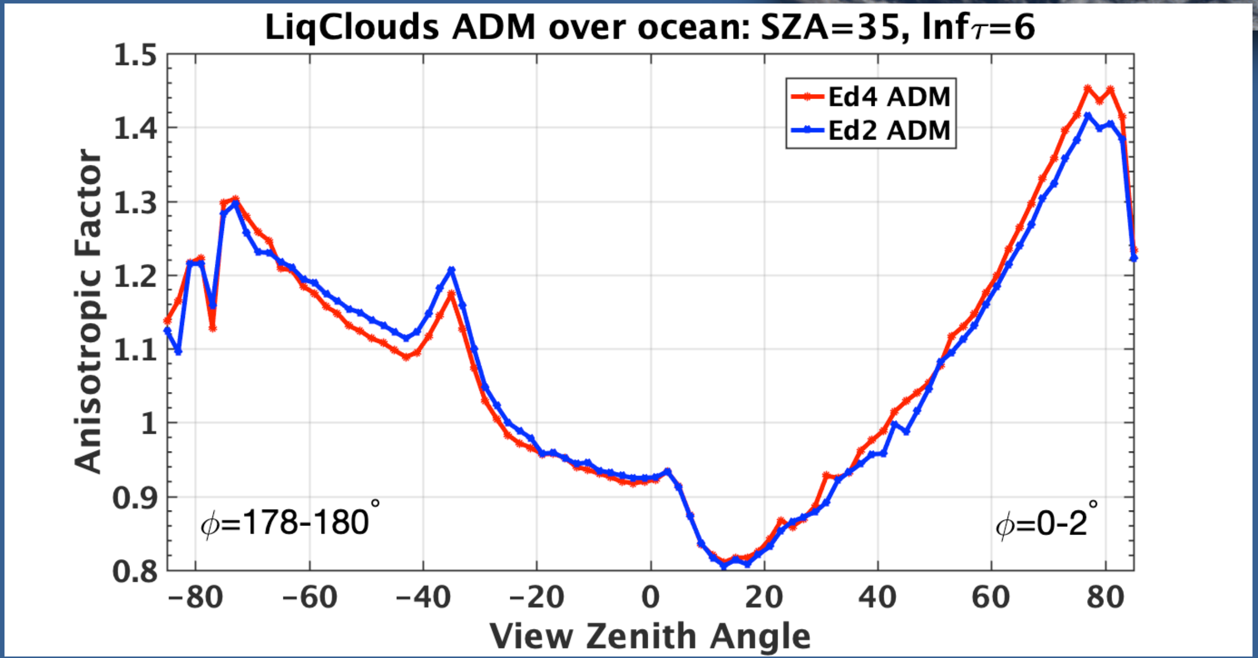


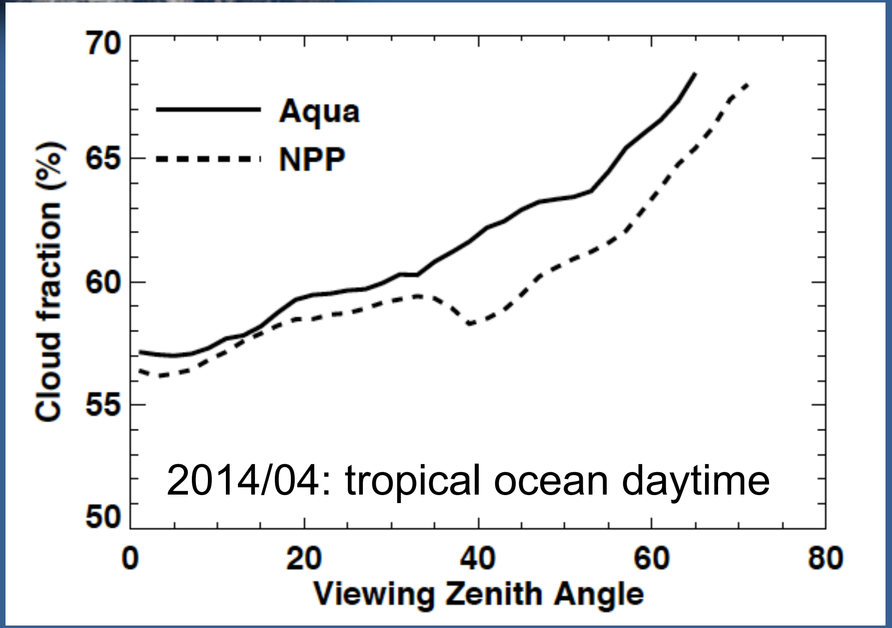
What constitute a given scene type depends on algorithm/imager

- The population for each scene type can change as algorithm/imager/input data changes

- The anisotropy characterized is algorithm-dependent

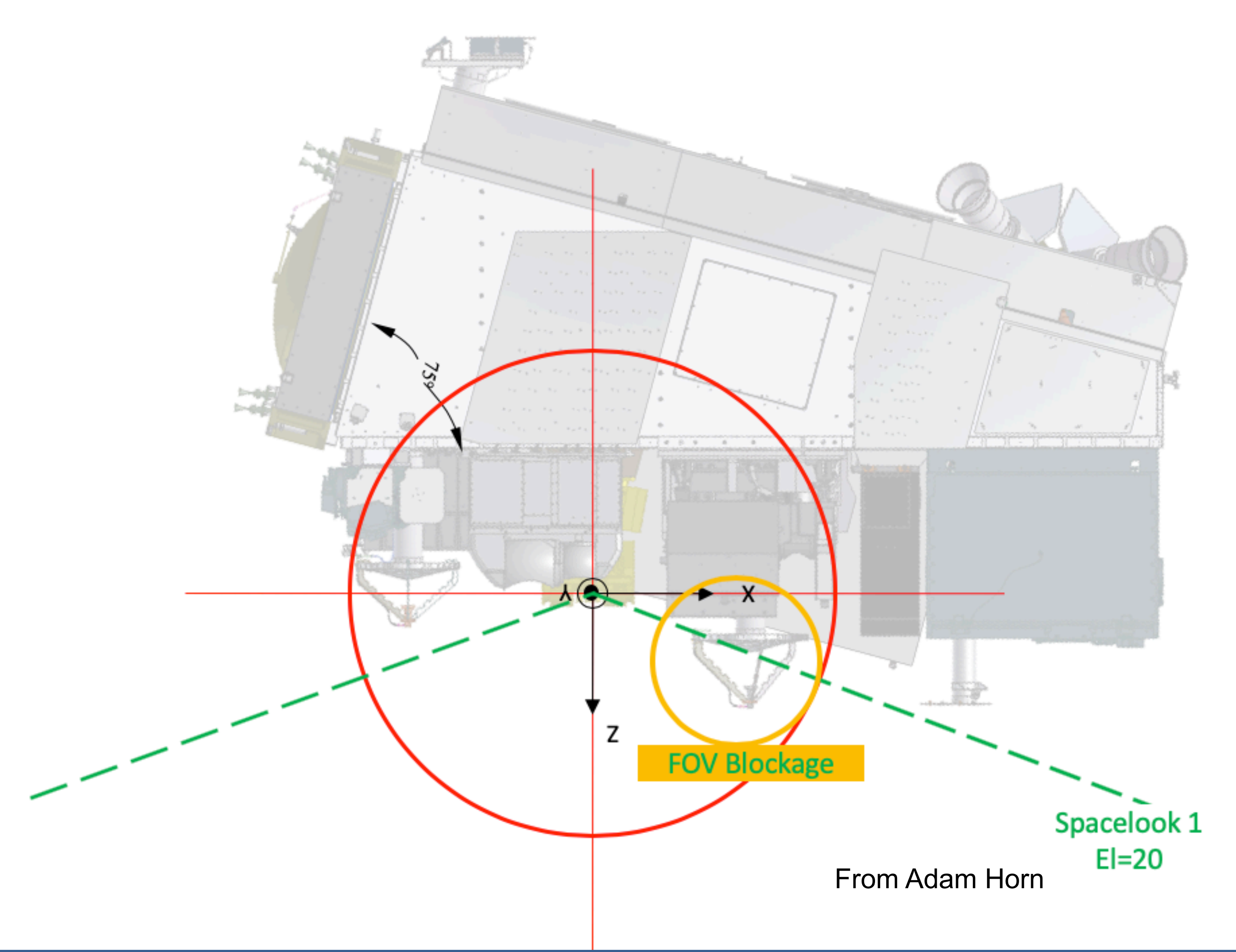






NPP is now collecting rotating azimuth plane (RAP) data

- CERES NPP was placed in biaxial mode to collect RAP data on August 19, 2019.
- As biaxial scan was not planned for CERES instrument on NPP, CERES instrument doesn't have an unobstructed view from all angles.
- There is an antenna at clock angle of ~20° on NPP. When CERES was first placed in biaxial scan mode, the antenna caused the total channel to reset. We thus had to terminate the biaxial scan.



NPP is now collecting rotating azimuth plane (RAP) data

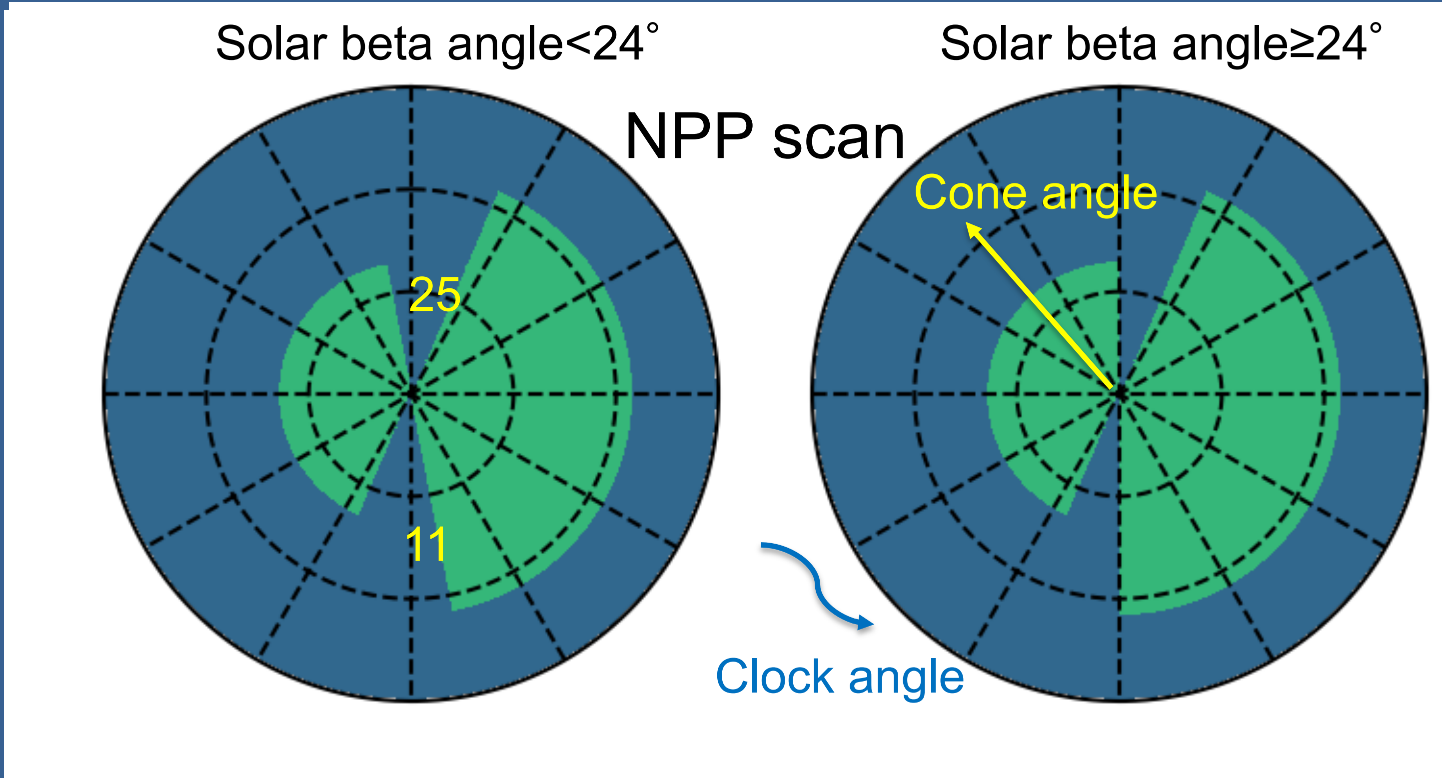
- The instrument team had to reprogram the scan to avoid the antenna and the biaxial scan resumed on October 1, 2019, only collecting restricted biaxial data in the clock angle ranges that avoid the antenna.
  - For solar beta angle < 24°:

    Clock angle: 25°-169°, cone angle: 0°-64°

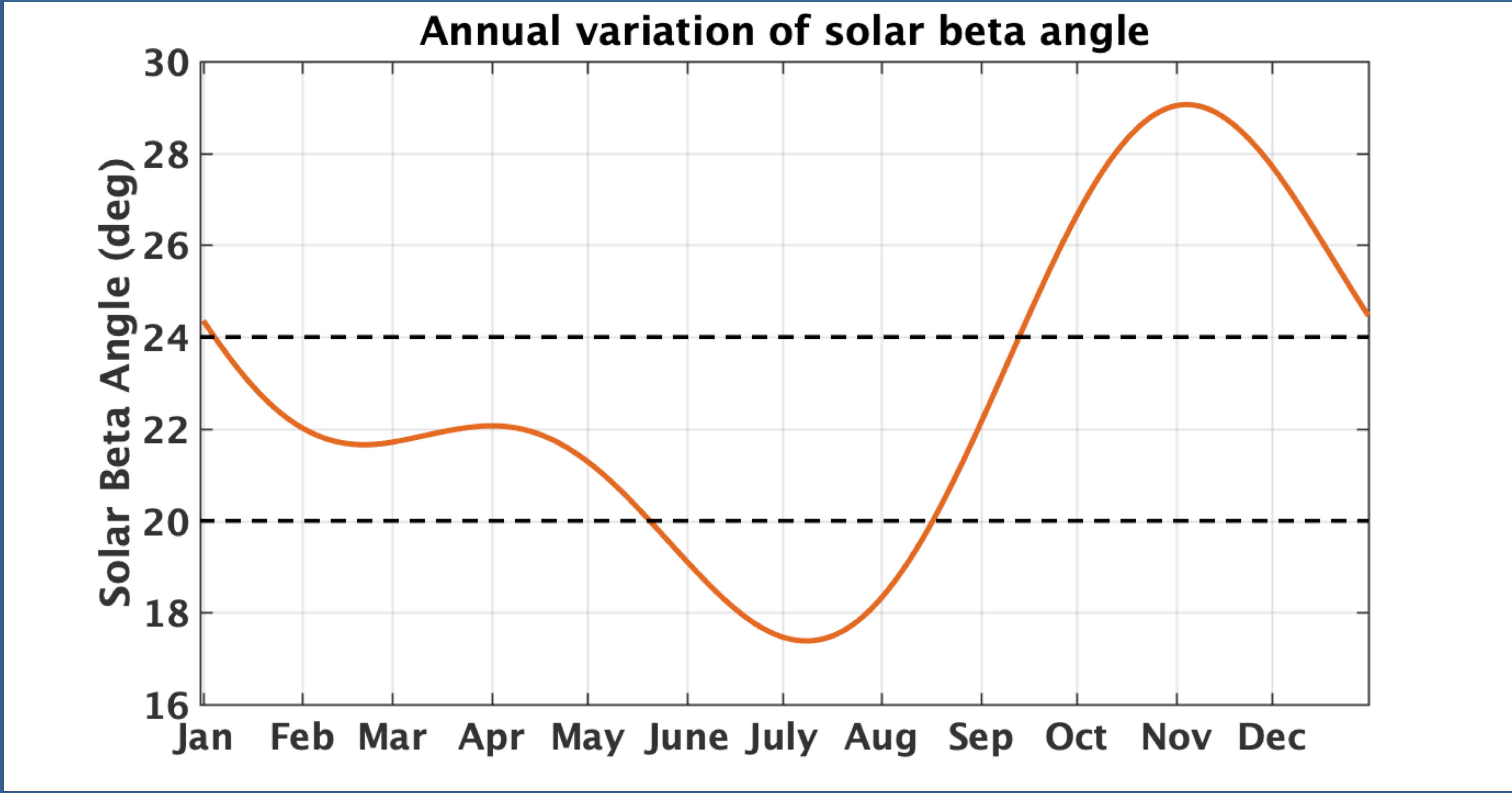
    Clock angle: 205°-349°, cone angle: 0°-38°
  - For solar beta angle ≥ 24°

    Clock angle: 25°-180°, cone angle 0°-64°

    Clock angle: 205°-360°, cone angle 0°-38°



Solar beta angle varies slowly throughout the year



RAPS data for CERES on Aqua

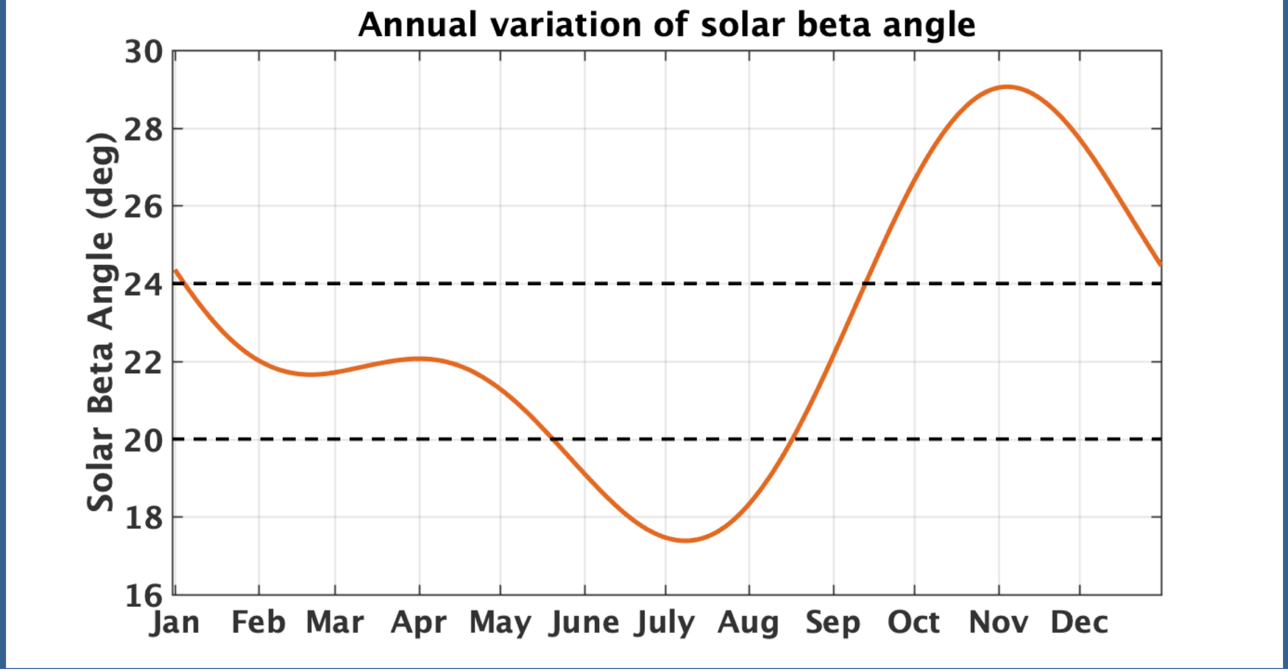
- About 30 months of RAPS data were collected by CERES instruments on Aqua
  - For solar beta angle < 20°:

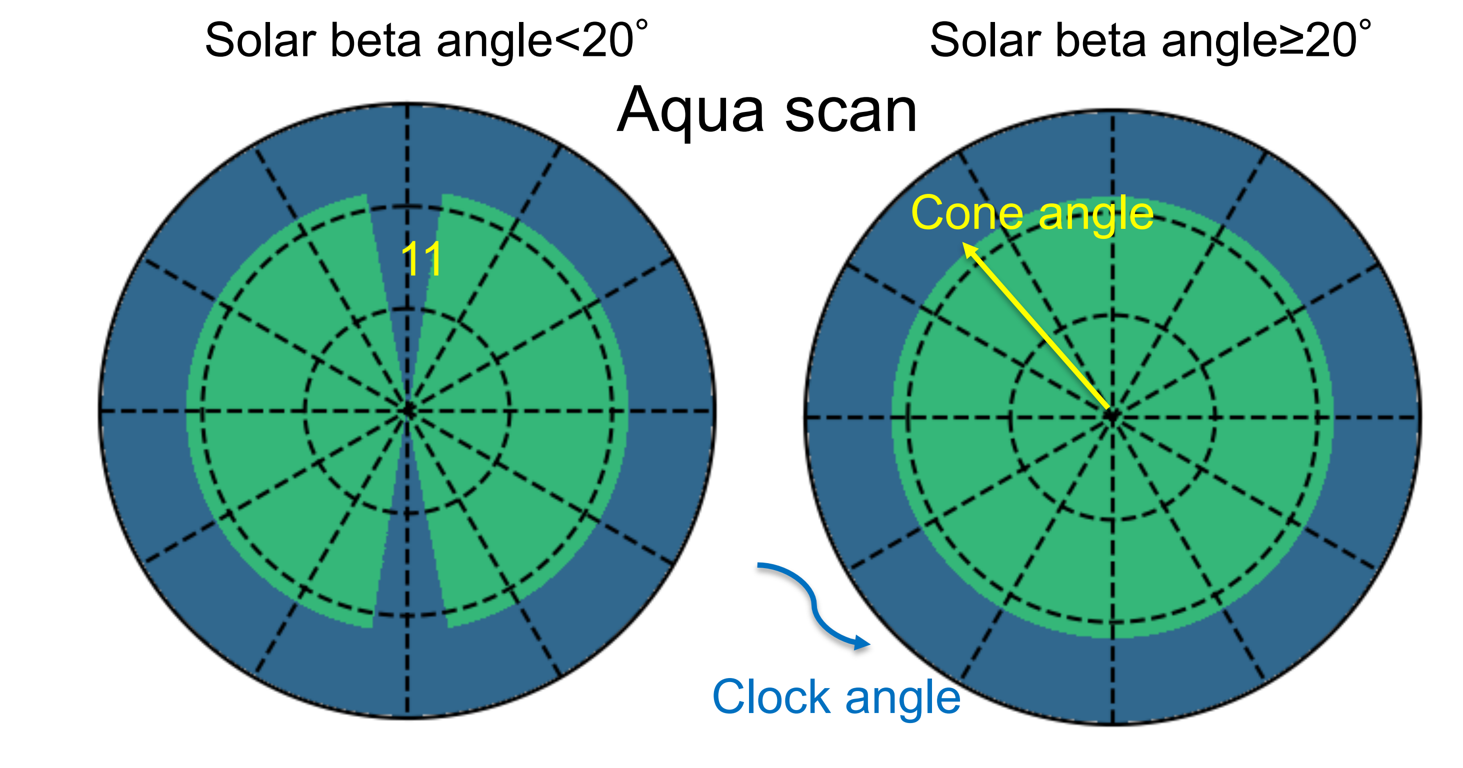
    Clock angle: 11°-169°, cone angle: 0°-64°

    Clock angle: 191°-349°, cone angle: 0°-64°
  - For solar beta angle ≥ 20°

    Clock angle: 0°-180°, cone angle 0°-64°

    Clock angle: 180°-360°, cone angle 0°-64°





Future plan for CERES NPP RAP scan

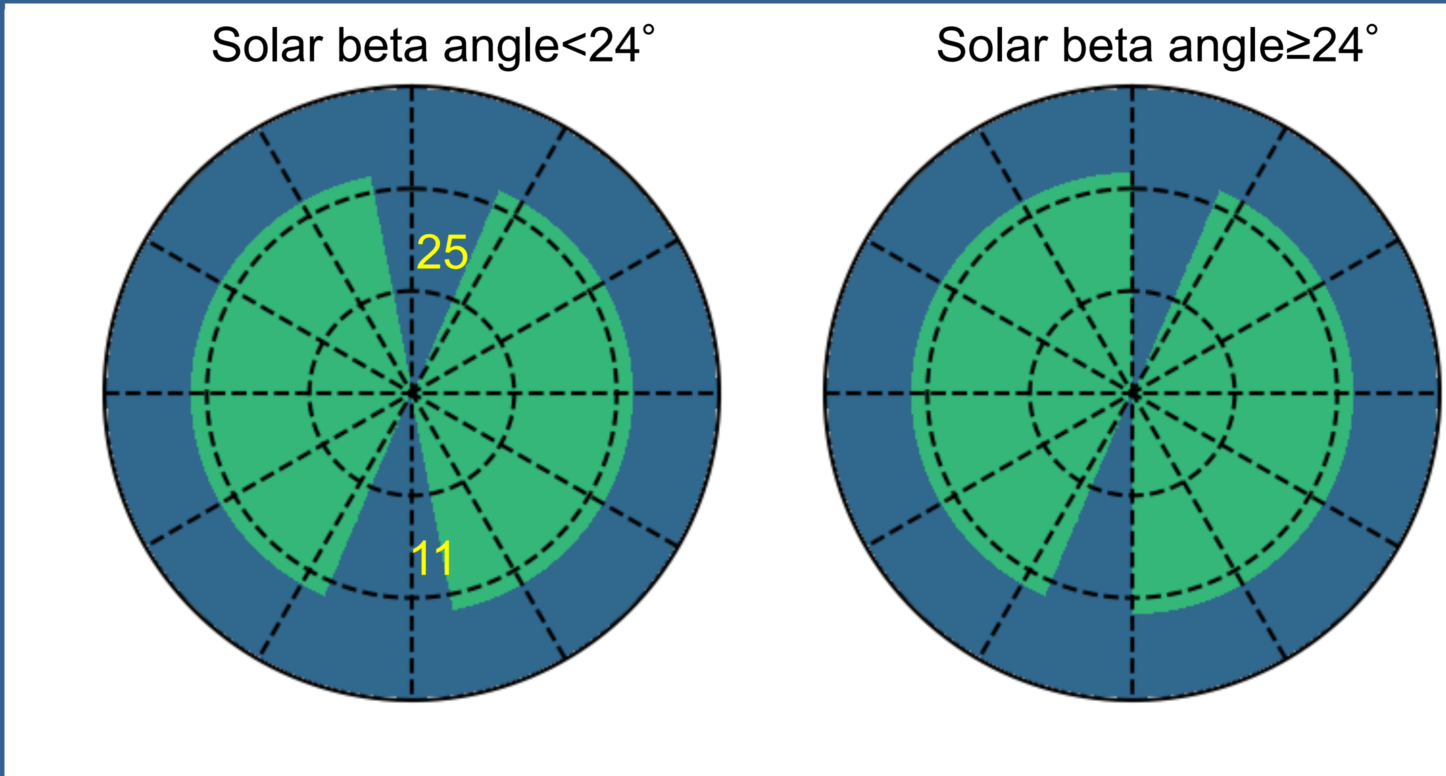
- To place the CERES instrument on normal biaxial scan, extra commands are needed to avoid the solar danger zone. Currently we are requesting more Detailed Activity Schedule (DAS) commands to program the instrument.
  - For solar beta angle < 24°:

    Clock angle: 25°-169°, cone angle: 0°-64°

    Clock angle: 205°-349°, cone angle: 0°-64°
  - For solar beta angle ≥ 24°

    Clock angle: 25°-180°, cone angle 0°-64°

    Clock angle: 205°-360°, cone angle 0°-64°

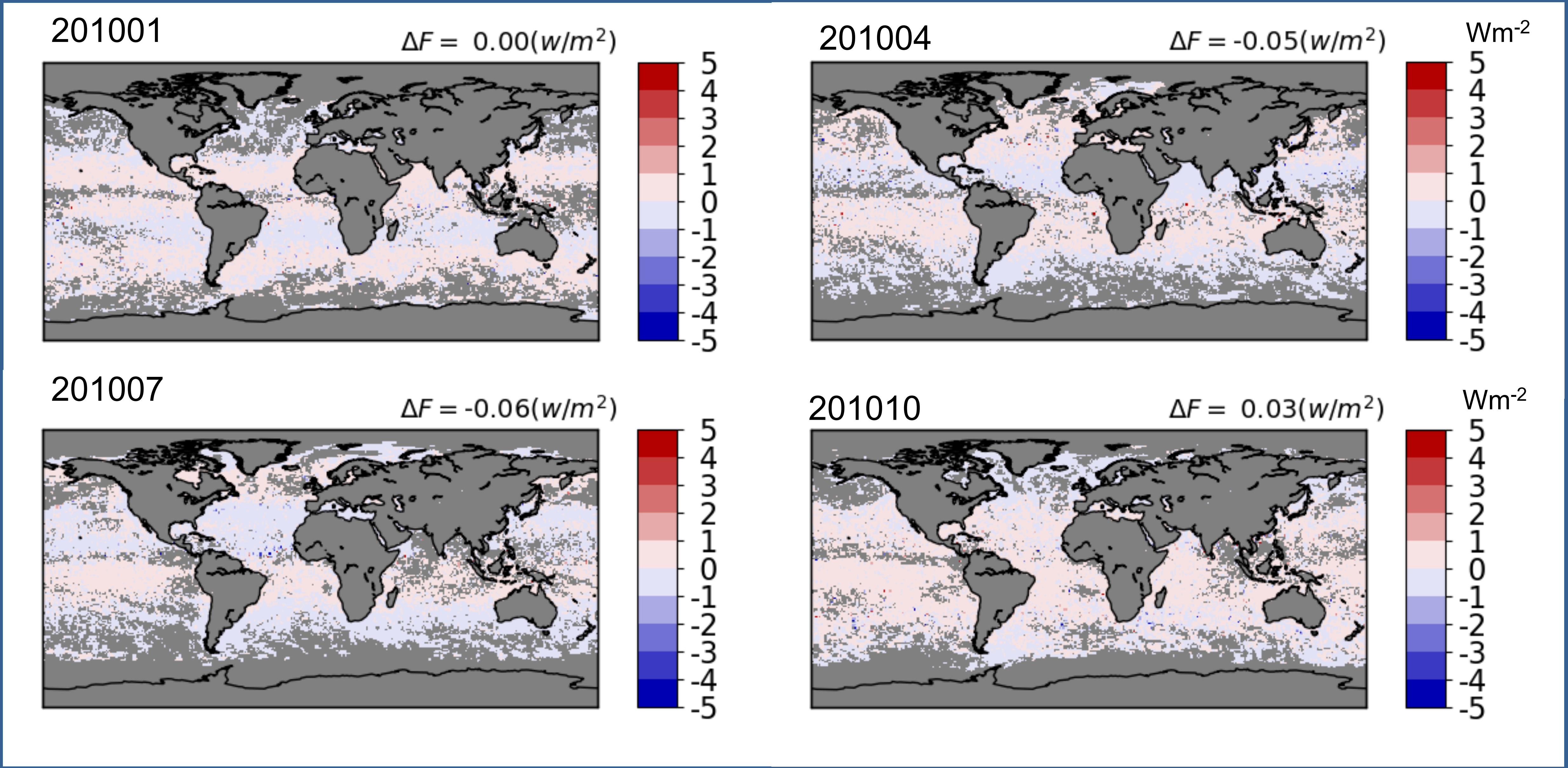


- Alternatively, we can extend the short scan on the sun side to the limb to extend the angular coverage.
- How big is the impact of the missing angles blocked by the antenna?

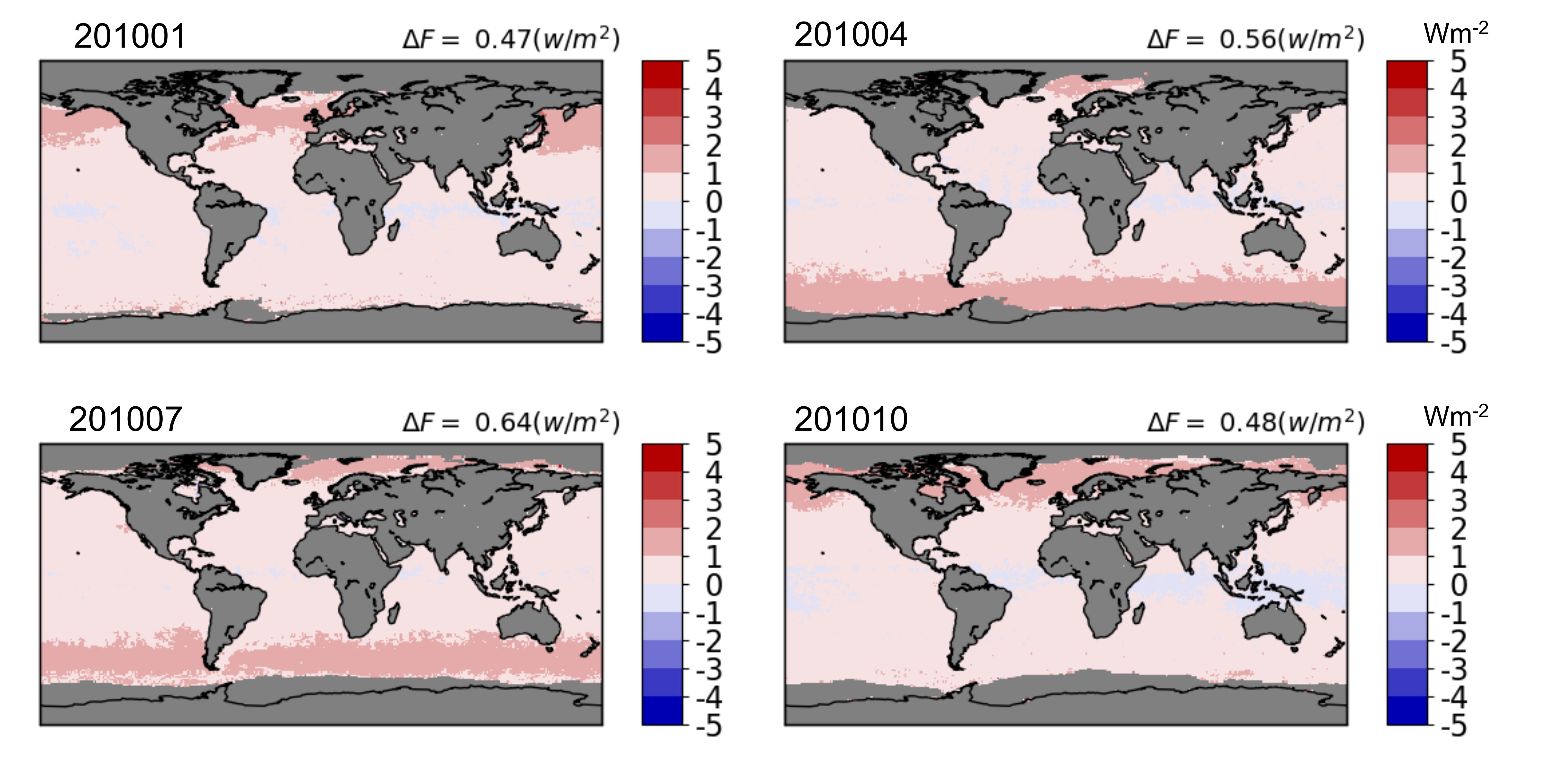
Assessing the effects of antenna blocked RAPS on ADM and on flux

- Construct two sets of ADMs using same code and same input files (2.5 years of RAPS and 2.5 years of cross track data from Aqua)
  - One set of ADMs use the full RAPS
  - The other set simulate the RAPS data will be collected on NPP
- Use these two sets of ADMs to invert fluxes: $F=\pi I/R$
- Examine the difference between flux inverted from these two sets of ADMs: ΔF = F(limited ADMs)-F(full ADMs)

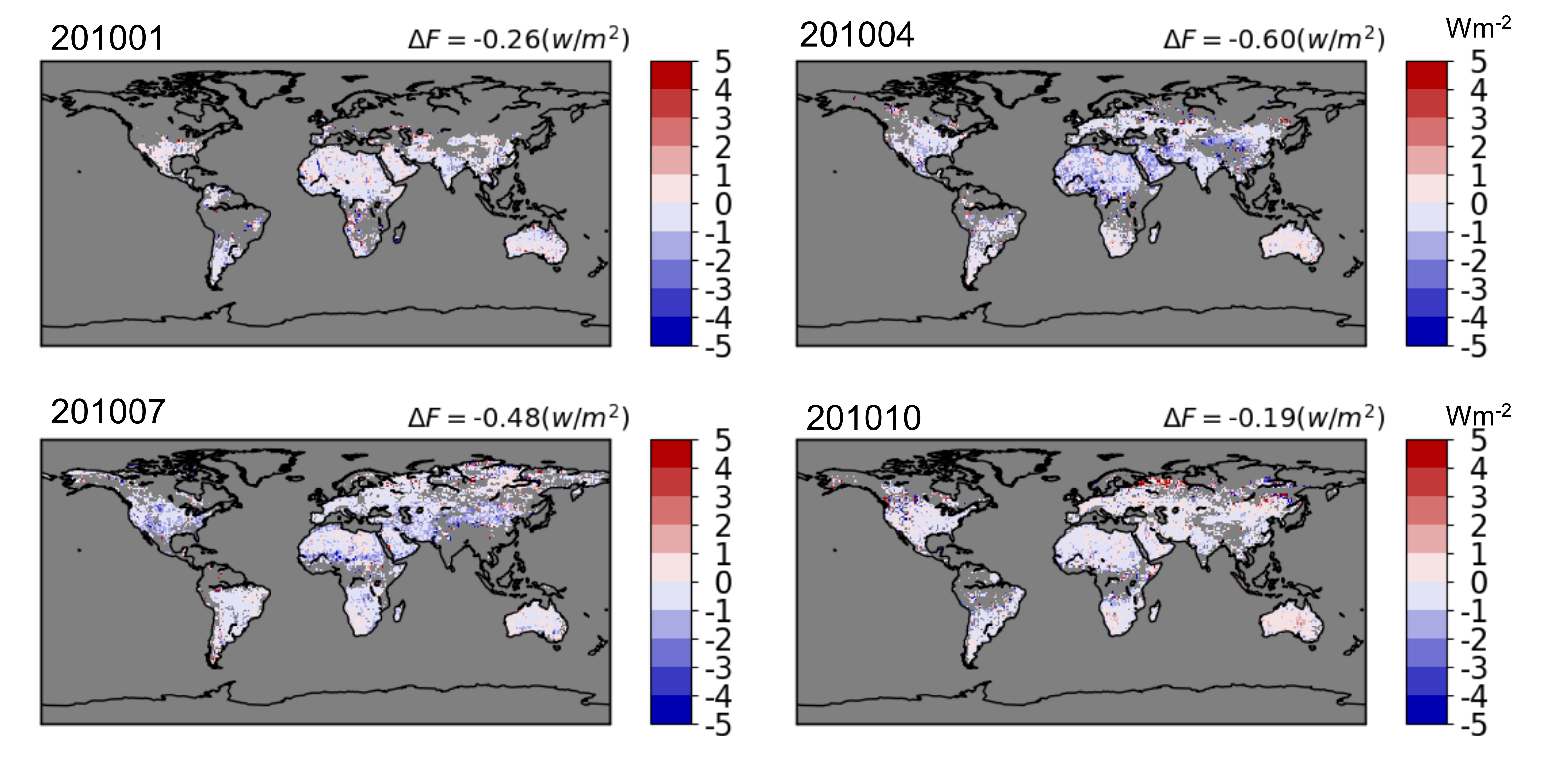
Monthly mean instantaneous SW flux difference over clear ocean



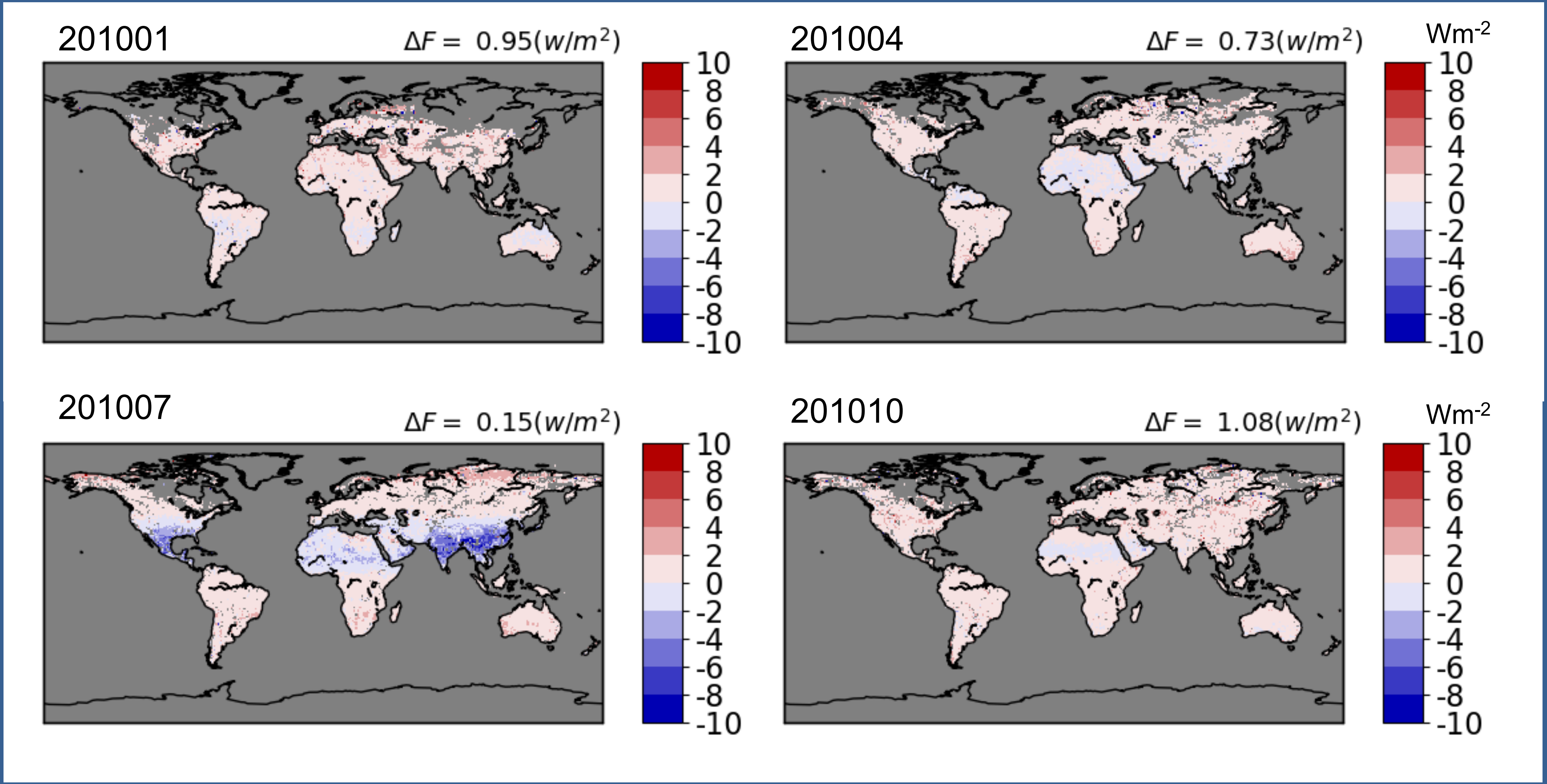
Monthly mean instantaneous SW flux difference over cloudy ocean



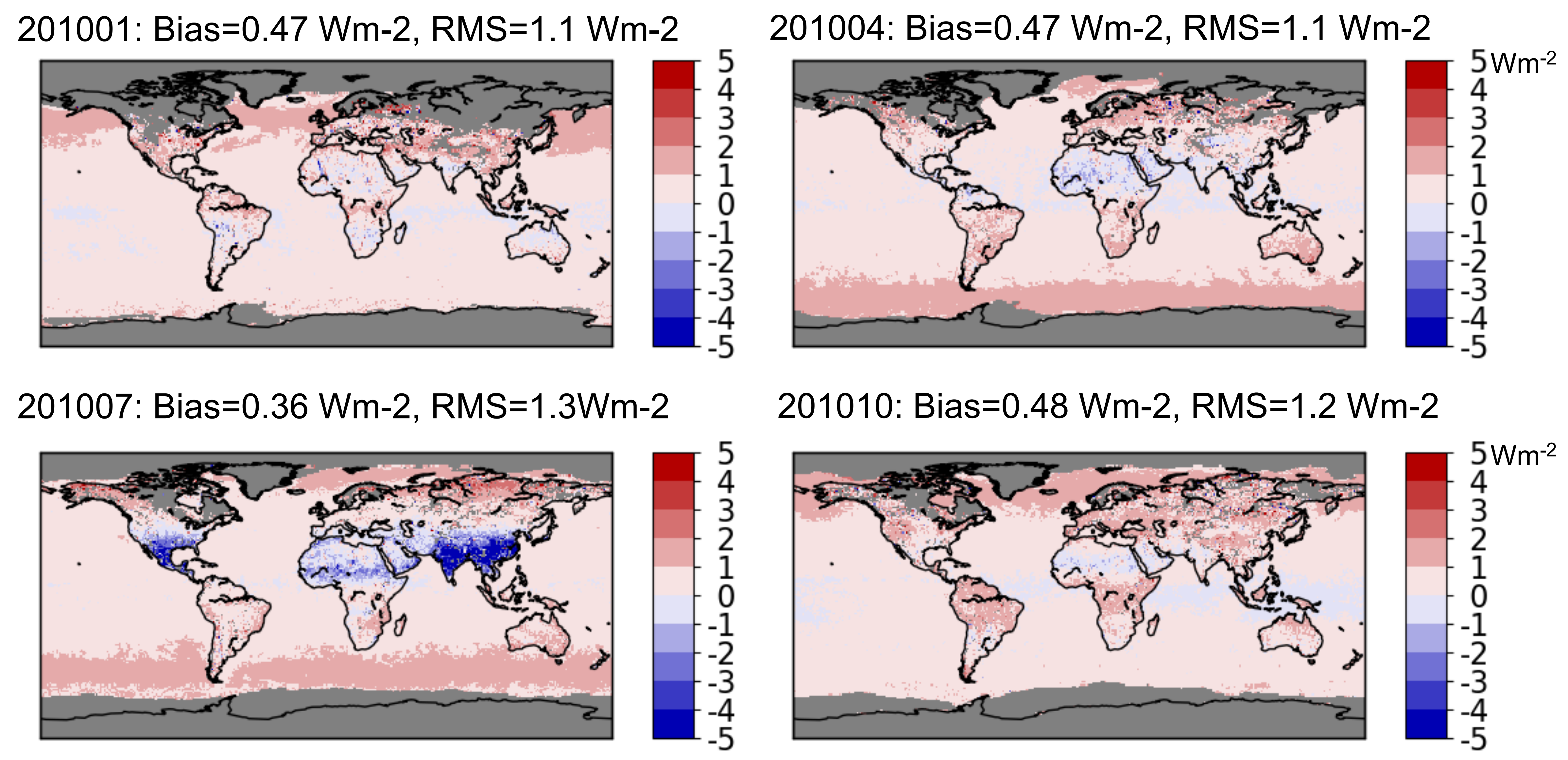
Monthly mean instantaneous SW flux difference over clear land



Monthly mean instantaneous SW flux difference over cloudy land



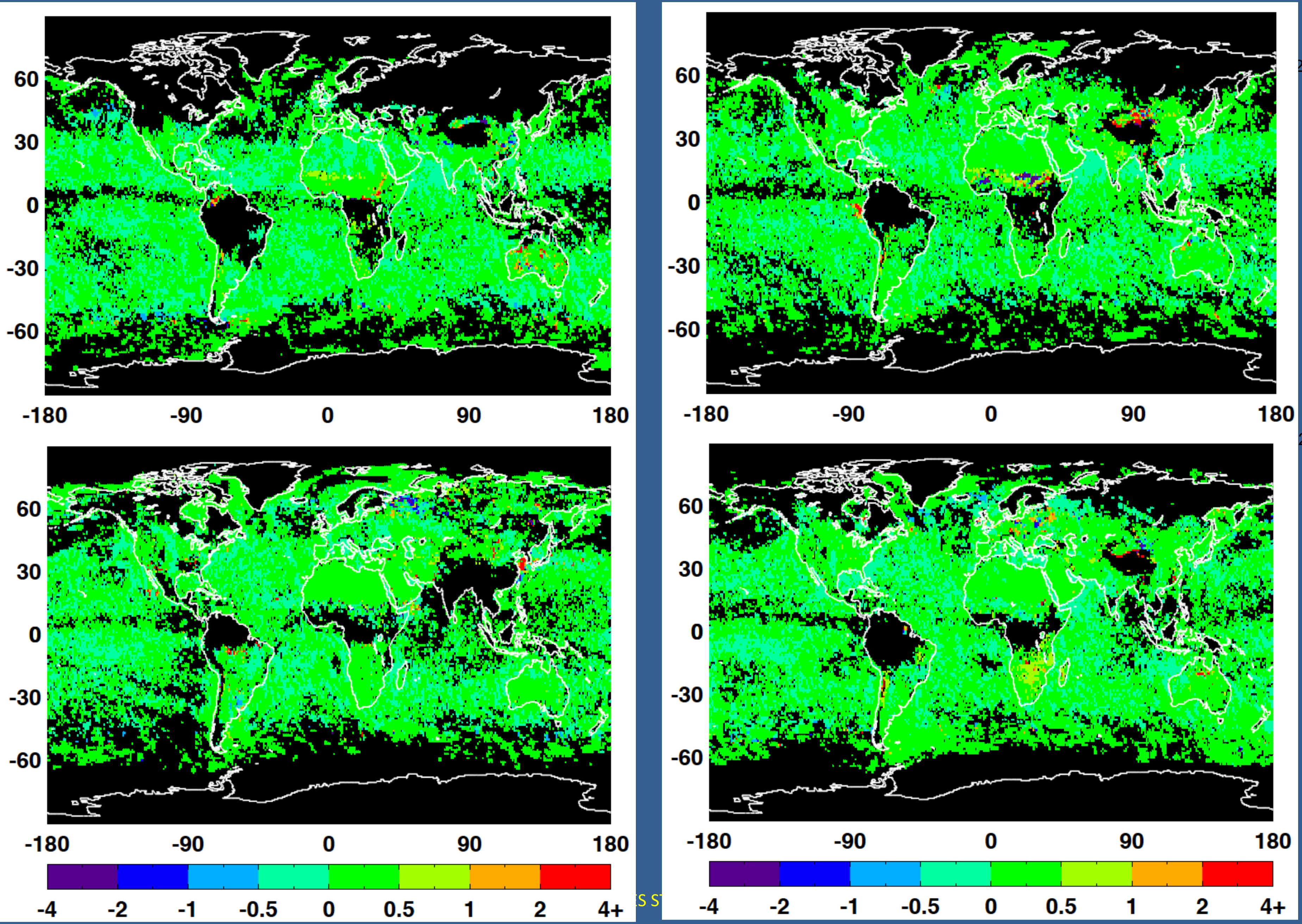
Monthly mean instantaneous SW flux bias and RMS error over land/ocean



Daytime clear-sky LW flux difference

Jan 2010:
ΔF = 0.05 W m^{-2}

Apr 2010:
ΔF = 0.06 W m^{-2}

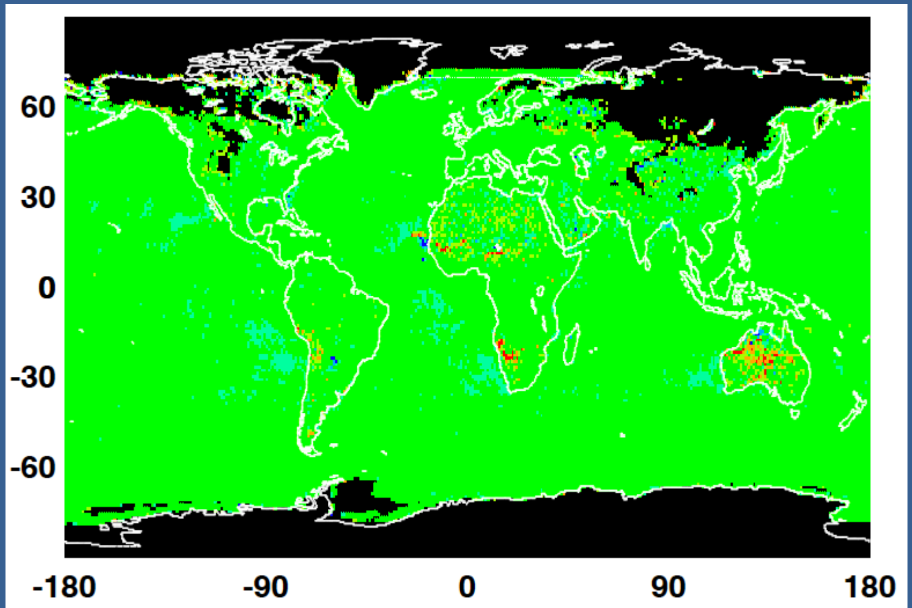


Jul 2010:
ΔF = 0.05 W m^{-2}

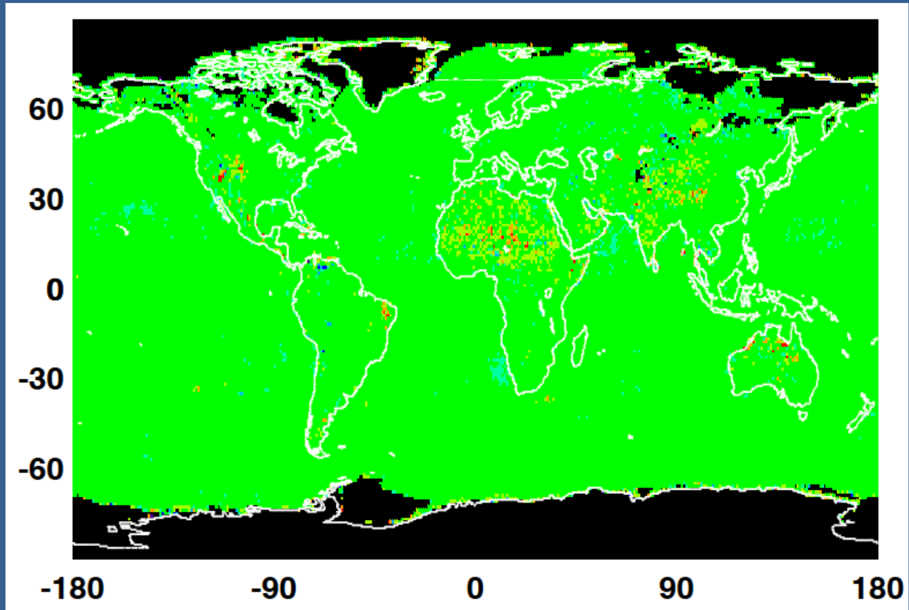
Oct 2010:
ΔF = 0.06 W m^{-2}

Daytime cloudy-sky LW flux difference

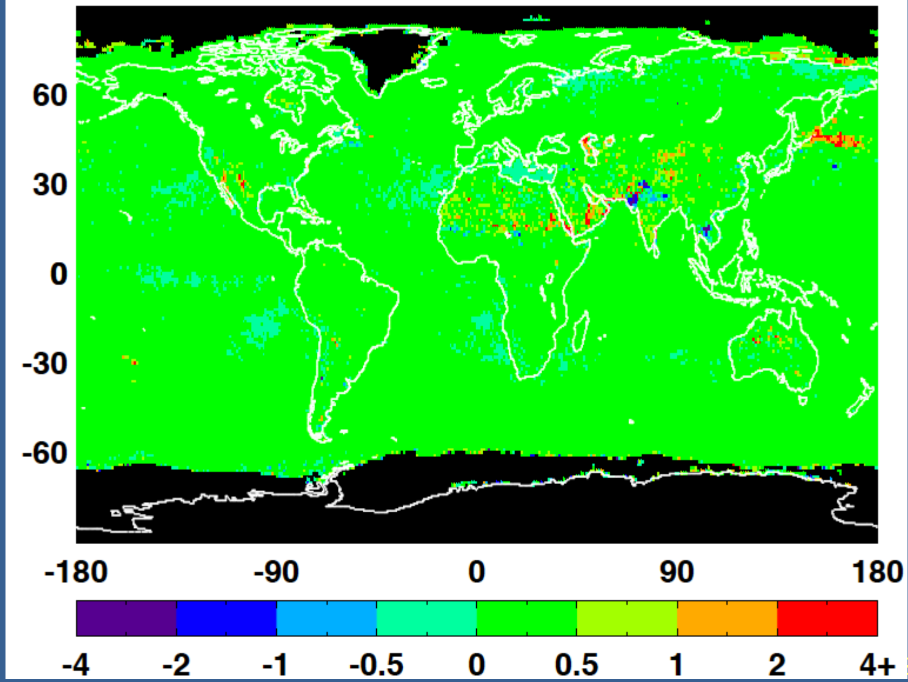
Jan 2010:
$\Delta F = 0.18$ W m^{-2}



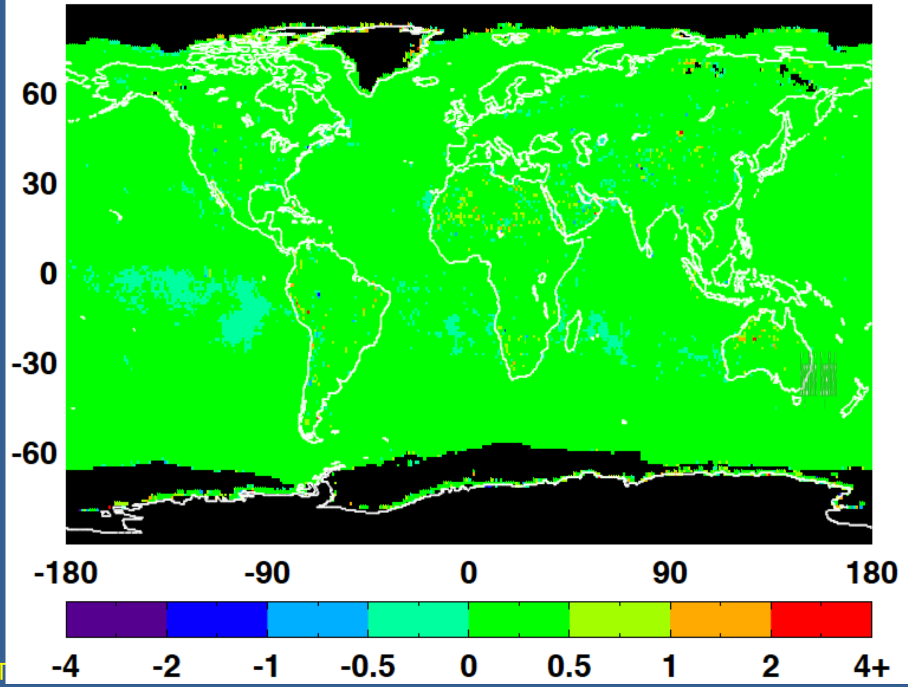
Apr 2010:
$\Delta F = 0.19$ W m^{-2}



Jul 2010:
$\Delta F = 0.18$ W m^{-2}



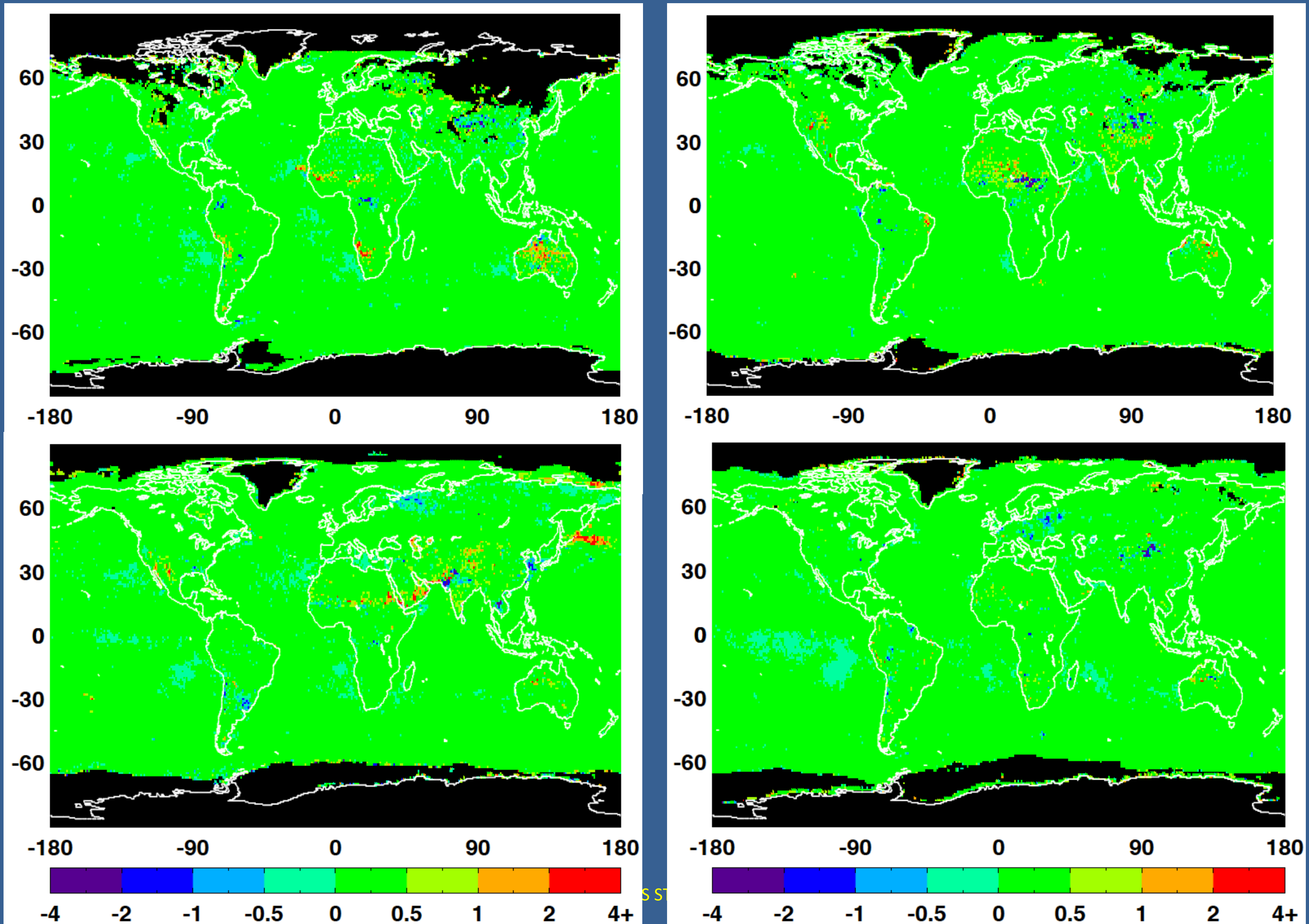
Oct 2010:
$\Delta F = 0.17$ W m^{-2}



Daytime all-sky LW flux difference

Jan 2010:
ΔF = 0.17 Wm^{-2}
RMS=0.28 Wm^{-2}

Apr 2010:
ΔF = 0.17 Wm^{-2}
RMS=0.31 Wm^{-2}



Jul 2010:
ΔF = 0.17 W m^{-2}
RMS=0.33 Wm^{-2}

Oct 2010:
ΔF = 0.16 Wm^{-2}
RMS=0.22 Wm^{-2}

Uncertainties of the monthly regional mean TOA fluxes: direct integration

		Terra 2002		Aqua 2004	
		Bias (Wm^{-2})	RMS (Wm^{-2})	Bias (Wm^{-2})	RMS (Wm^{-2})
SW	January	0.04	0.97	0.11	1.00
	April	0.08	0.79	-0.16	0.75
	July	-0.20	1.08	0.11	0.90
	October	0.02	0.65	0.15	0.78
LW	January	0.37	0.72	0.29	0.64
	April	0.47	0.76	0.37	0.60
	July	0.44	0.78	0.31	0.71
	October	0.39	0.65	0.36	0.61

LW ADMs over clear land

- Over land, the clear-sky LW ADMs are defined for five surface types: grassland/cropland, forests, savannas, dark deserts, and bright deserts.
- Over each surface type, the LW ADMs were developed for discrete intervals of precipitable water (w), lapse rate (ΔT), and surface skin temperature (Ts) as a function of viewing zenith angles.
- Others (Minnis and Kyaiyer, 2000; Minnis et al., 2004) noted that the shadowing by vegetation and landforms can cause azimuthal variations of the LW radiance and the surface skin temperature (Scarino et al. 2017).

w (cm)	ΔT (K)	T_s (K)
0–1	< 15	< 260
1–3	15–30	260–340 every 10 K
3–5	30–45	> 340
> 5	> 45	

Anisotropy correction for surface temperature retrieval

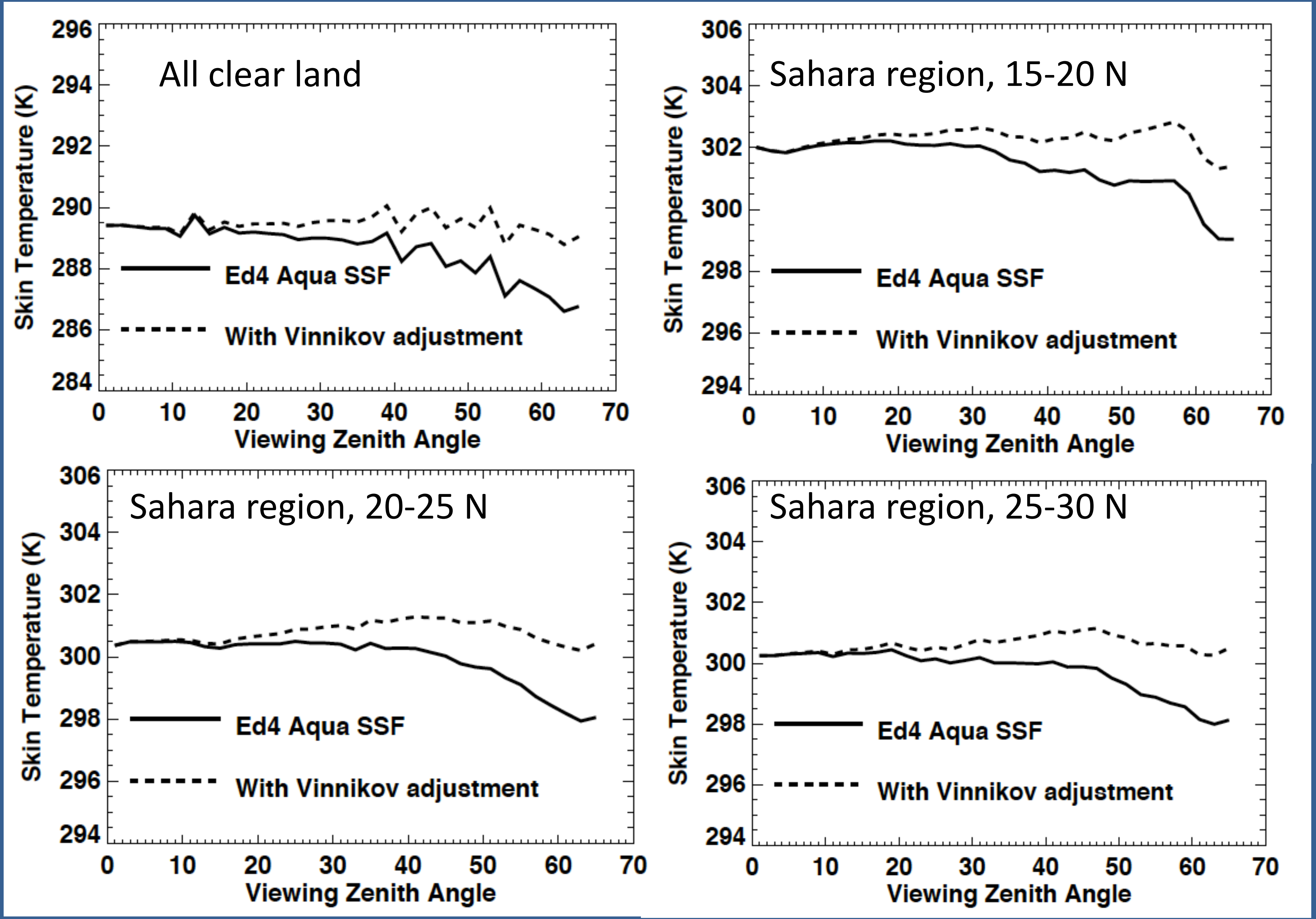
- Surface skin temperature retrievals based on 11 μm radiances are affected by variations in emissivity with viewing zenith angles and also by solar geometry during daytime (Vinnikov et al. 2012).
- Vinnikov et al. (2012) used one full year of simultaneous observations by GOES-E and GOES-W at the SURFRAD locations to develop a kernel-based anisotropy model for land surface temperature:

$$T_s(\theta, \theta_0, \phi) = T_n + T_n[\underbrace{a(1 - cos\theta)}_{\text{Emissivity kernel}} + \underbrace{b\psi(\theta, \theta_0, \phi)}_{\text{Solar kernel}}]$$

- Scarino et al. (2017) applied this anisotropy model to GOES-E and GOES-W and found that this correction improves the agreement between them and with other independent surface temperature dataset.
- Cloud working group has applied this anisotropy correction model to surface temperature retrievals based upon GEO satellite observations, but not yet to MODIS/VIIRS.

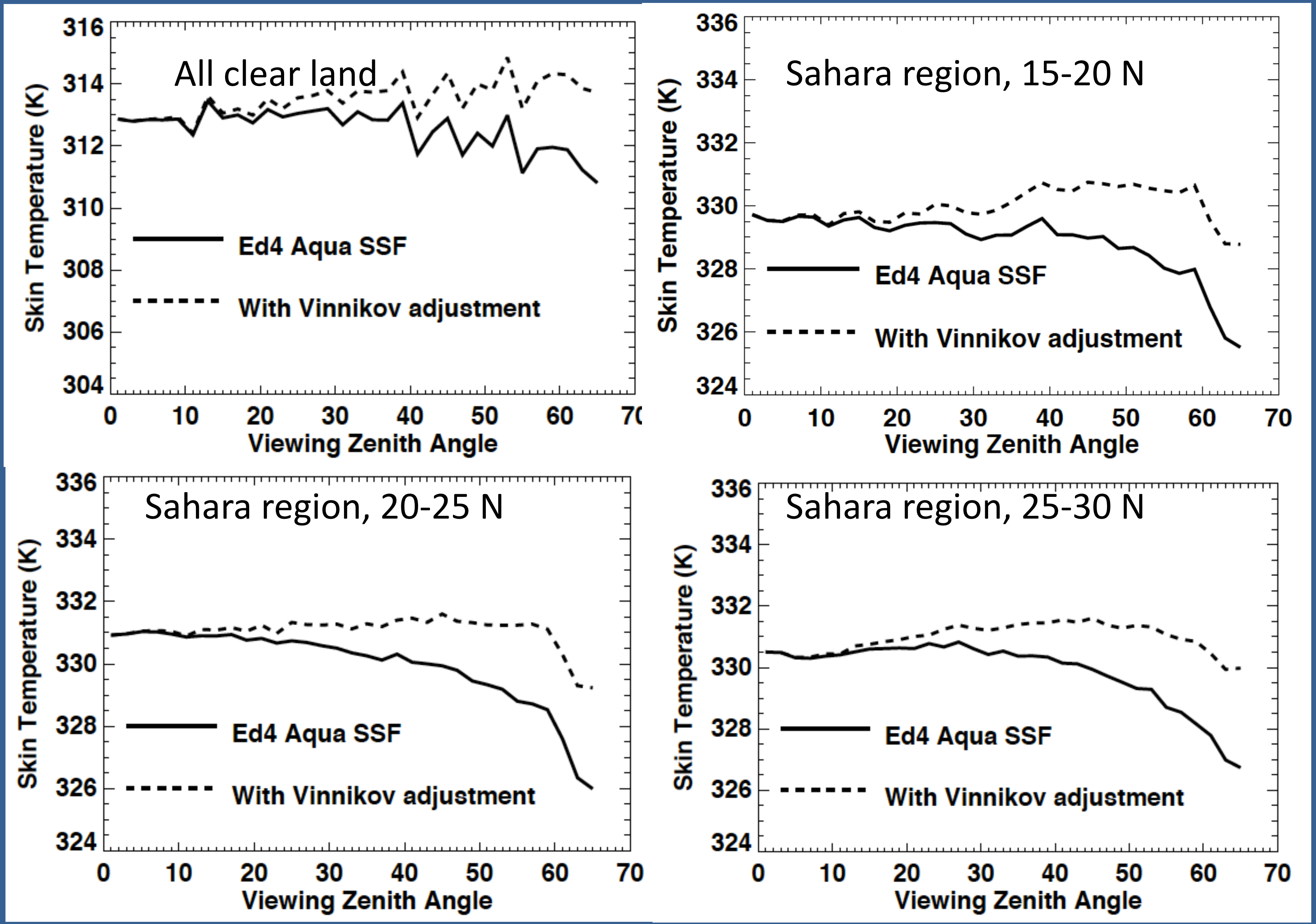
Apply anisotropy correction model to imager-based surface skin temperature in SSF: Nighttime Ts with emissivity correction show less variation with VZA

Aqua July 2008 nighttime Ts

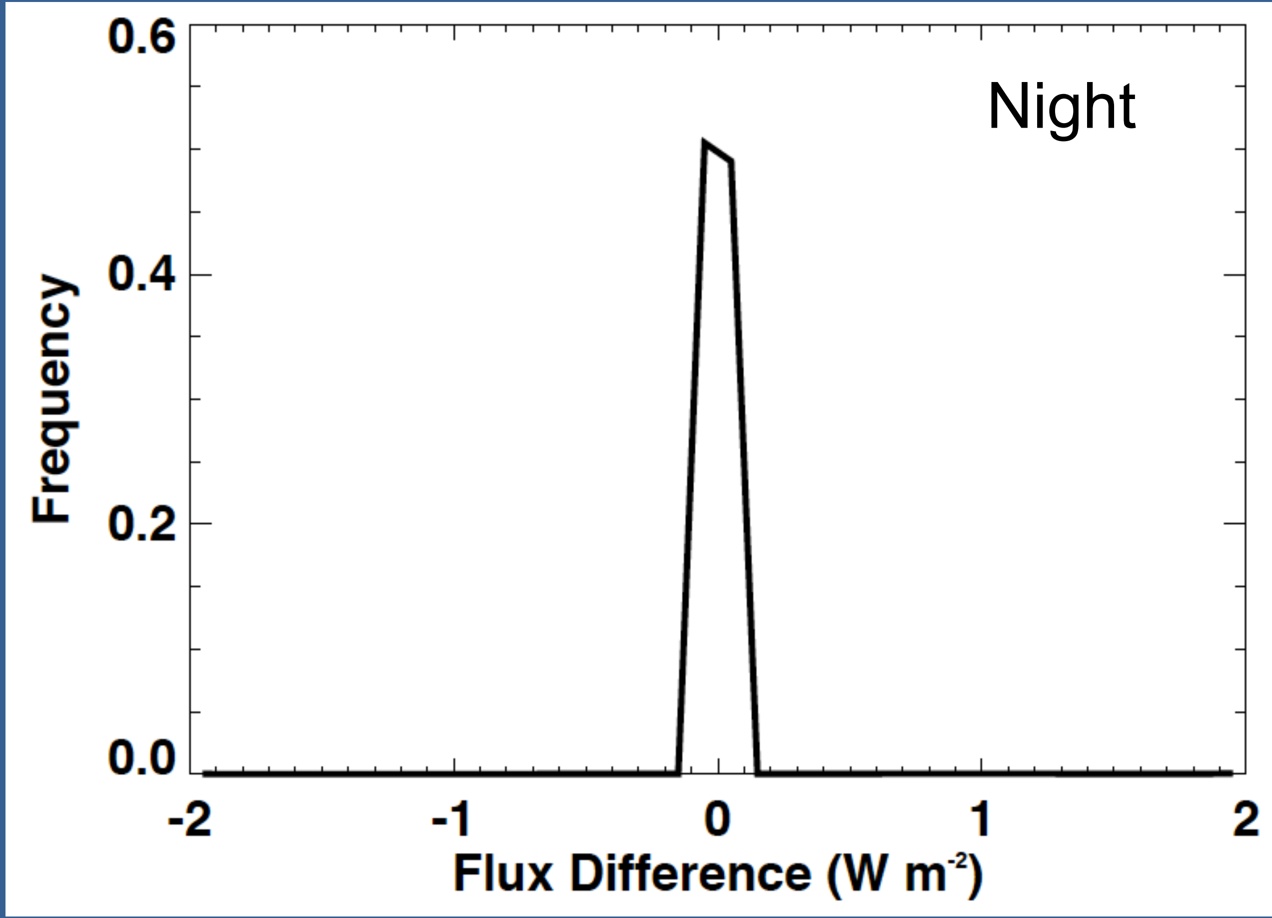


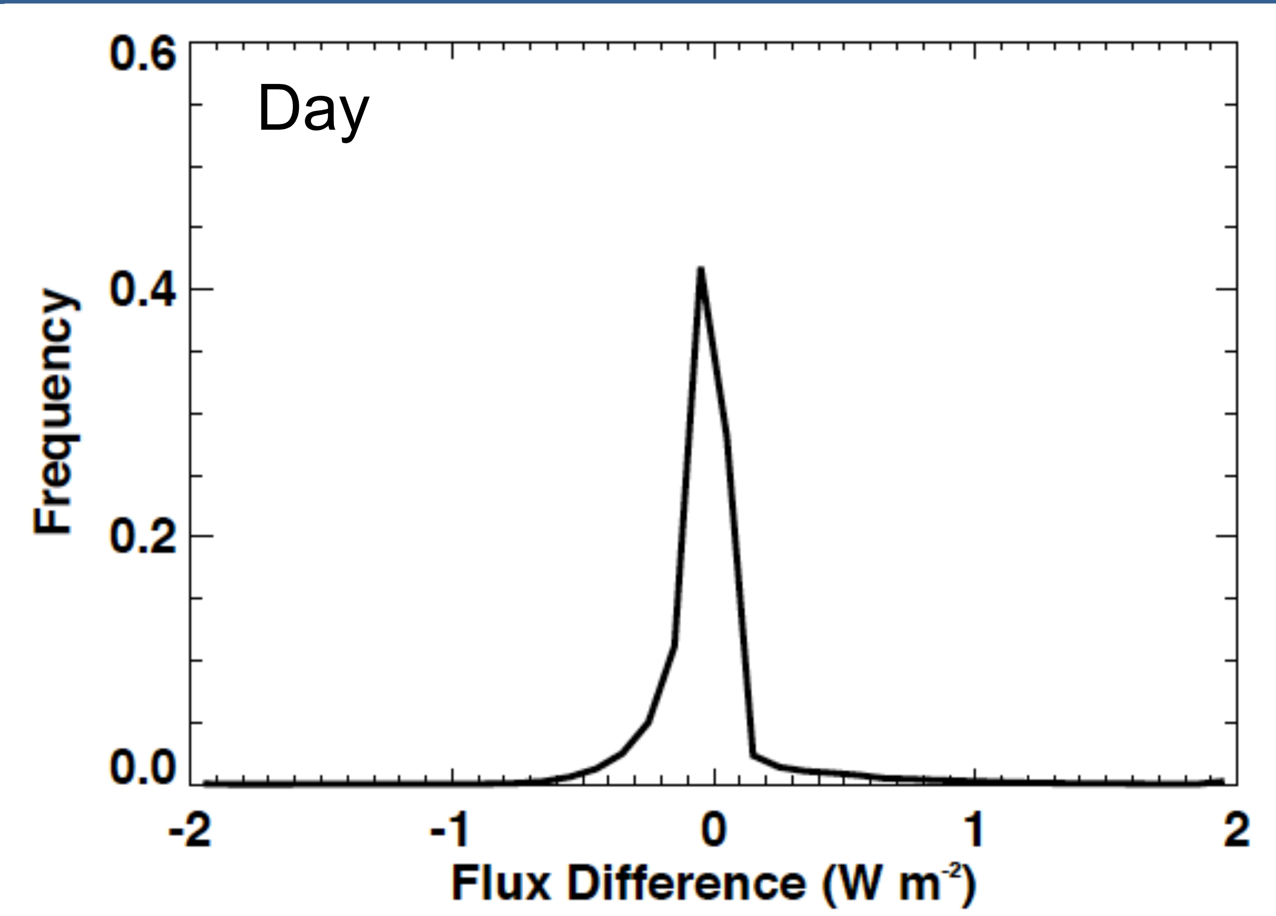
Apply anisotropy correction model to imager-based surface skin temperature in SSF: Daytime Ts with emissivity and solar correction show less variation with VZA

Aqua July 2008 daytime Ts



The anisotropy corrected Ts has minimum impact on LW flux inversion



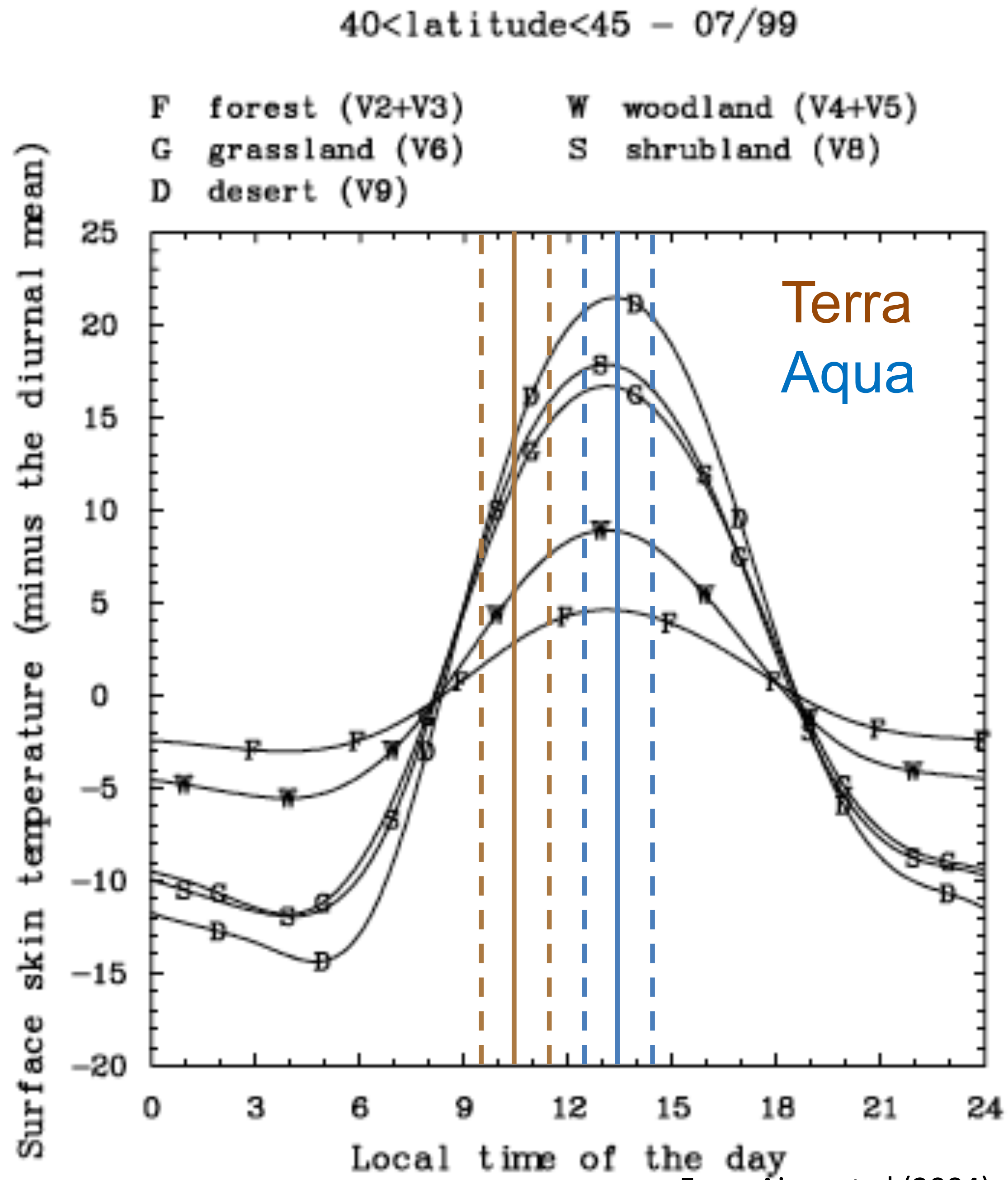


Very small impact on July 2008 nighttime fluxes – most differences are less than 0.1 W m^{-2}

Small impact on July 2008 daytime fluxes – most differences are less than 0.5 W m^{-2}

Azimuthal dependency of the clear-sky daytime ADMs

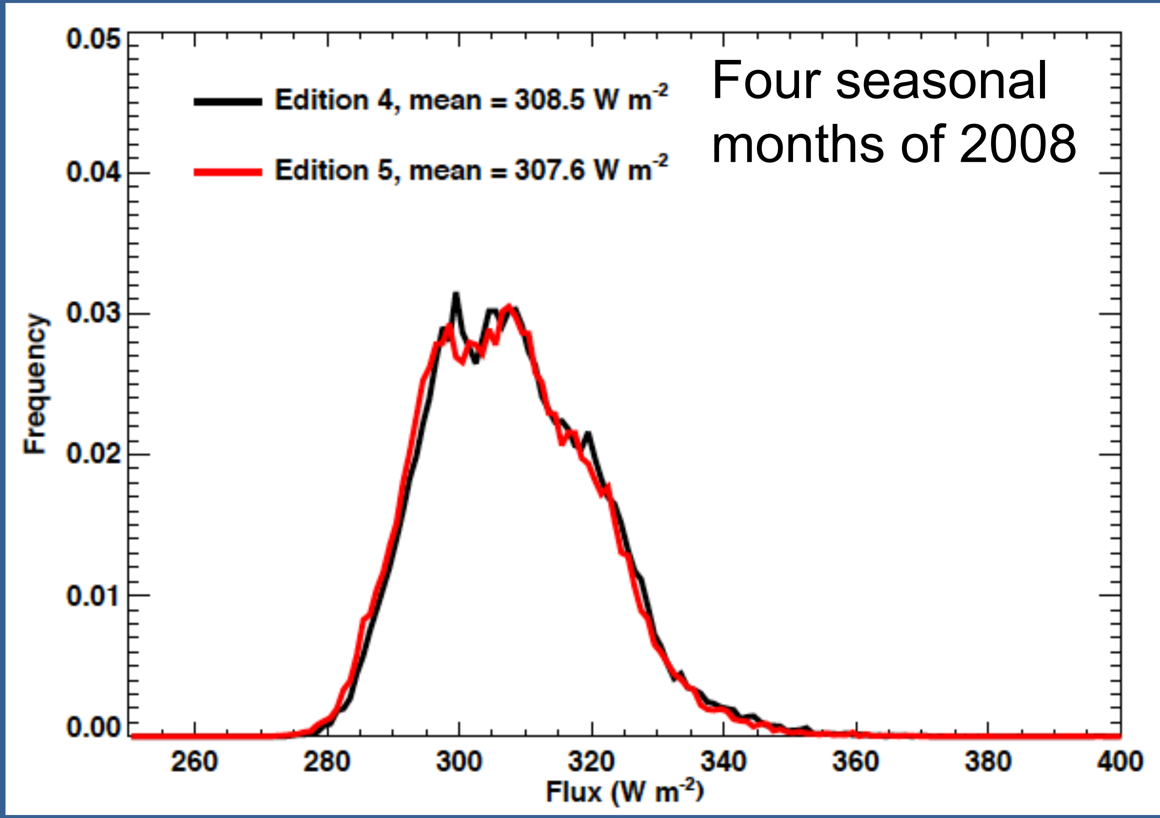
- Examine the sensitivity of daytime LW ADMs to solar zenith angle, relative azimuth angle, and surface variability (SV) following the method used in Minnis et al. (2004).
- As Terra/Aqua are in Sun-synchronous orbit, the scan to the east of the satellite are always observing areas at an earlier local time than those to the west of the satellite. Under clear conditions, the mean surface temperature to the east of the satellite should be greater than that to the west of the satellite.
- The east-west temperature contrast is larger for Terra, and relative small for Aqua.

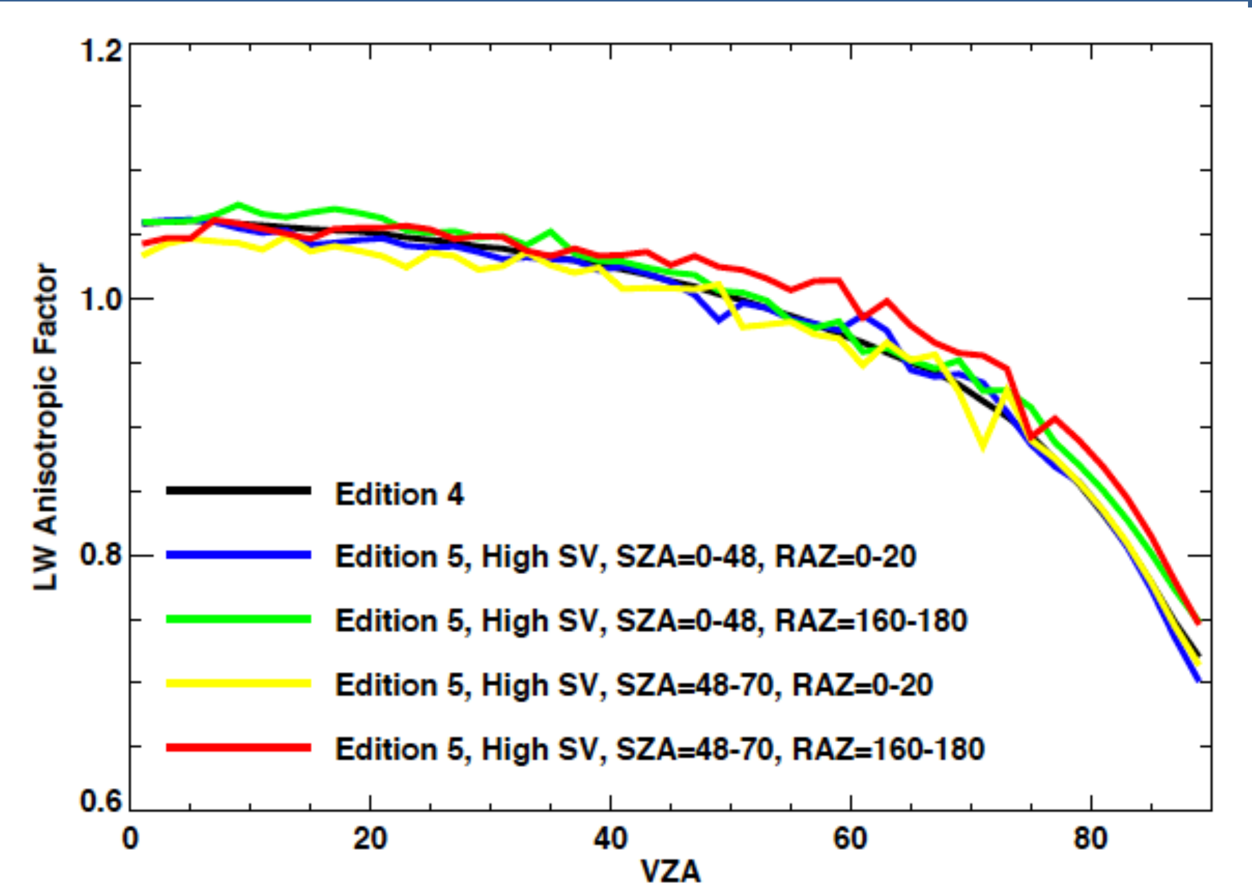


From Aires et al (2004)

Aqua clear-sky LW ADM dependency on solar zenith angle, relative azimuth angle, and surface variability

- Crops/Grasslands: PW=1-3cm, ΔT=15-30 K, Ts=300-310 K
- LW anisotropic factors show some sensitivity to SZA/RAA
- Impact on flux is small: RMS=2 Wm-2



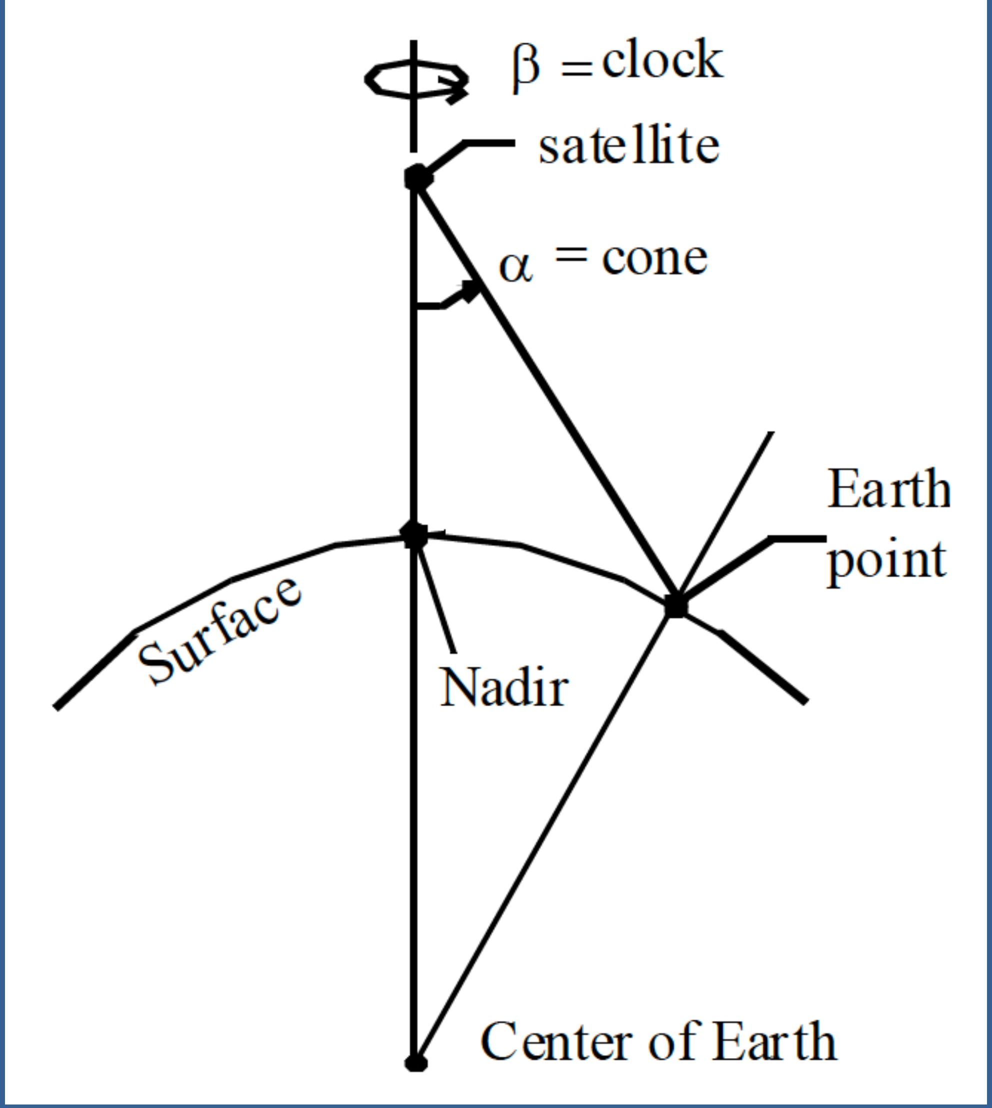


Summary

- CERES on NPP started taking RAPS data. Only limited scan data are taken at the moment, plans are underway to collect full RAPS scan minus the antenna blockage data in the near future
- Aqua RAPS data are used to simulate the NPP RAP scan
- Fluxes inverted using ADMs developed with the simulated NPP RAP are compared with fluxes inverted using ADMs developed with the full RAP
  - Monthly mean instantaneous SW flux differences are less than 0.5 Wm-2 with RMS error ~1 Wm-2
  - Monthly mean daytime LW flux differences are less than 0.2 Wm-2 with RMS error ~0.3 Wm-2
- Surface skin temperature retrieved by considering the variations in emissivity with viewing zenith angles and also by solar geometry during daytime show smaller dependency on VZA
- Including the anisotropy correct for surface temperature has minimum impact on LW flux inversion
- Clear-sky LW anisotropy shows some sensitivity to Sun-viewing geometry, but the impact on flux inversion is small

Cone and clock angle

- The cone angle is the angle between a vector from the satellite to the center of the Earth and the instrument view vector from the satellite to the Earth point (ranges from 0° to 90°). The cone angle is related to the viewing zenith angle.
- The clock angle is the azimuth angle of the instrument view vector from the satellite to the Earth point relative to the inertial velocity vector (ranges from 0° to 360°). The clock angle is related to the relative azimuth angle.
- The clock angle and the cone angle define the direction of the instrument view vector to the Earth point.



From SSF Collection Document

Relationship between viewing zenith angle and cone angle, between relative azimuth angle and clock angle for full RAPS